The Journal of the Elisha Mitchell Scientific Society, 102(3), 1986, pp. 122–128

DETECTABILITY OF A REDUCTION IN A SINGLE YEAR CLASS OF A FISH POPULATION

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Abstract: Catastrophic mortality of young-of-the-year fishes through massive fish kills, large-scale pollution events, or outbreaks of disease are often cited as likely causes of reduced abundance in future years. We use the Atlantic menhaden (*Brevoortia tyrannus*) fishery as a test analytical situation to assess the ability of researchers to detect a reduction in a single year class of a fish stock resulting from a one time event. The observation in 1984 and 1985 of large fish kills in North Carolina estuarine areas and high incidence rate of ulcerative lesions in young-of-the-year menhaden from Florida to New Jersey prompted this study. Recruitment to the fishery of age-1 fish and catch in numbers at age-2 are used as indices of post-impact year class abundance. Based on natural logarithmic transforms of the above indices, estimates of statistical power (i.e., probability of correctly detecting a reduction in year class abundance from one of the above indices) are developed. The results suggest that only truly catastrophic reductions in year class abundance (>70%) or catch at age-2 (>40%) are likely to be detected. The occurrence of any confounding source of mortality will make it more difficult to detect a reduction due specifically to the cause of mortality under investigation.

Key Words: menhaden; *Brevoortia tyrannus*; population studies; fish mortality.

INTRODUCTION

Catastrophic mortality of young-of-the-year fishes through massive fish kills, large-scale pollution events, or outbreaks of disease are often cited as likely causes of reduced abundance in future years. The question often arises whether there will be an observable reduction in the fish stock or in the fish landings when a large fish kill occurs. In this paper a statistically appropriate method is applied to assess a researcher's ability to detect a reduction in a single year class resulting from either a natural or a man-induced catastrophic event, such as the sudden outbreak of disease or an oil spill. This report follows up on a theoretical concern raised in Schaaf et al. (1987) concerning the ability to detect reductions in populations following acute pollution events because of variability in young-of-the-year survival.

The recent outbreak of ulcer-type lesions, or ulcerative mycosis (Dykstra et al., 1986; Noga and Dykstra, 1986) in young-of-the-year Atlantic menhaden has raised a concern about the effect of this disease on future landings and stock size. Large mortalities of young-of-the-year Atlantic menhaden were noted in pound nets in the Pamlico River, North Carolina, during the fall of 1984. Incidences of this disease have been found primarily in low to moderate salinity (0–7 ppt). *Aphanomyces* species (water mold) have been cultured from the lesions, but it is not definite whether the lesions are caused by the *Aphanomyces* or result from some general stress syndrome.

The biology of the Atlantic menhaden is described in detail in Reintjes (1969). Atlantic menhaden are filter-feeding planktivores which range from Florida to Nova Scotia. They migrate north in the spring and south in the fall with older and larger menhaden migrating farther north (Nicholson, 1978). Some spawning occurs year round, but the majority of spawning activity occurs offshore during the late fall and winter off North Carolina. Eggs develop into larvae, and larvae enter estuarine nursery grounds. After metamorphosis into juveniles and growth during the summer season, young menhaden typically migrate to sea during late fall. Menhaden are caught primarily by purse seine and are currently landed at six menhaden processing plants from Fernandina Beach, Florida, to Rockland, Maine, for reduction to fish meal and oil. In recent years most of the landings have been made at Reedville, Virginia, and Beaufort, North Carolina.

METHODS

Two historical data sets are used as indices of abundance for the Atlantic menhaden stock: catch in numbers at age-2 and recruitment in numbers to age-1. Because age-2 Atlantic menhaden represent the first fully recruited age class in the landings, estimates of purse seine catch in numbers at age-2 would provide the earliest indication of a significant effect of ulcerative mycosis in young-of-the-year menhaden to the entire Atlantic menhaden stock (young-of-the-year menhaden in 1984 would be landed as age-2 fish in 1986). Annual estimates of catch in numbers of age-2 Atlantic menhaden have been available since 1955 and serve as an index of abundance for age-2 menhaden. The data (Table 1) are restricted to the period 1973 to 1983 due to technological improvements and geographic and temporal changes in fishing effort. Virtual population analysis has been used to estimate annual recruitment to age-1 for Atlantic menhaden year classes from 1955 to 1979 (Table 2) (Ahrenholz et al., 1987). These estimates serve as an index of abundance for age-1 menhaden. An estimate of recruitment to age-1 for the 1984 year class would not be available before completion of the 1989 fishing season when that year class would be landed as age-5 menhaden. The estimate of catch in numbers of age-2 menhaden is preferred over the estimate of recruitment to age-1 because of the shorter time-lag in detecting a reduction in the fishable stock due to the outbreak of ulcerative mycosis.

The analytical approach follows that outlined in Vaughan and Van Winkle (1982). That approach uses the noncentral-t distribution to determine the sample size and associated statistical power required to detect a reduction in an index of population abundance of white perch (*Morone americana*) resulting from power plant operation. This report is concerned with detecting losses to a single year class through recruitment to age-1 and resultant losses in fishery landings from that year class when it later enters the fishery as age-2 menhaden. Hence, the sample size for future observations (n_2 in Vaughan and Van Winkle) is one.

The null hypothesis is that there is no impact or reduction in numbers of young-of-the-year Atlantic menhaden resulting from ulcerative mycosis, while the set of alternative hypotheses consists of increasing levels of reduction in the 1984 year class. The type I error is defined as the probability of incorrectly rejecting the null

Table 1
Catch in numbers of age-2 Atlantic menhaden (in millions) for the period 1973 through 1983.

Year	Catch of Age-2	ln (Catch of Age-2)
1973	1,145.4	7.044
1974	984.6	6.892
1975	1,087.8	6.992
1976	1,343.3	7.203
1977	2,079.4	7.640
1978	1,668.6	7.420
1979	1,594.0	7.374
1980	1,461.7	7.287
1981	1,802.1	7.497
1982	1,737.0	7.460
1983	2,282.2	7.733
Mean	1,562.4	7.322
Standard deviation	409.5	0.268
Coefficient of variation	0.262	0.037

hypothesis when the null hypothesis is true, and the type II error is defined as the probability of incorrectly accepting the null hypothesis when one of the alternative hypotheses is true. The power of a statistical test (1 − type II error) is the probability of correctly rejecting the null hypothesis and, hence, correctly detecting a reduction in the 1984 year class presumably due to ulcerative mycosis.

RESULTS

Power curves (Figs. 1A, 2A) for detecting a reduction in the Atlantic menhaden stock are based on historical data on catch in numbers at age-2 and recruitment to age-1 (Tables 1, 2). Because of the relatively large coefficient of variation (CV) associated with these data, statistical power is poor even for relatively large impacts (i.e., a large reduction in the 1984 Atlantic menhaden year class as indicated by a large reduction in catch in numbers at age-2 or in recruitment to age-1). For type I error = 0.05 (standard for most statistical testing), a 50% reduction in the 1984 Atlantic menhaden year class prior to age-1 due to ulcerative mycosis would be necessary to have a 52% chance of detecting a reduction in abundance of age-2 menhaden from the 1984 year class (based on estimates of catch in numbers in age-2). A similar reduction has only a 15% chance of detection as a reduction in abundance of age-1 menhaden (based on estimates of recruitment to age-1) and is possible only four to five years later.

The sensitivity of the statistical test is improved through natural logarithmic transformations of the original data sets (Tables 1, 2). Power curves based on the transformed data were developed (Figs. 1B, 2B). The transformed and original data sets were tested for normality using the Kolmogorov goodness of fit test (Conover, 1971); only the untransformed recruitment at age-1 data was rejected (type I error = 0.1) as being normally distributed. Because of the significant reduction in the coefficient of variation (CV), statistical power is apparently improved by working with transformed data. However, it must be kept in mind that a 50% fractional reduction in transformed data corresponds to a much greater

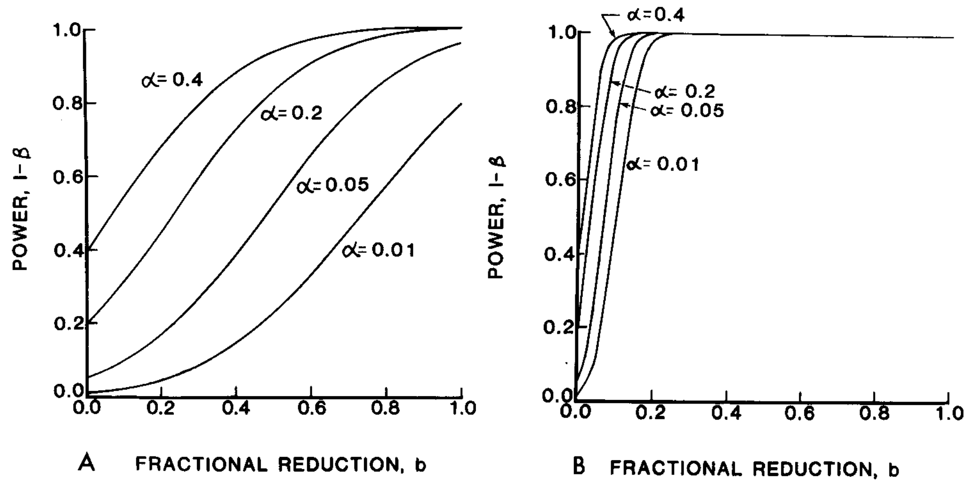

FIG. 1. Statistical power for testing the fractional reduction in abundance of age-2 Atlantic menhaden measured as (A) catch in numbers at age-2 with a coefficient of variation (CV) equal to 0.262 and 10 degrees of freedom and (B) natural logarithm of catch in numbers at age-2 with a CV equal to 0.037 and 10 degrees of freedom. Curves are presented for four levels of type I error (0.01, 0.05, 0.2, 0.4).

fractional reduction in the untransformed data (i.e., for either catch in numbers at age-2 or recruitment to age-1). If b′ is the fractional reduction in the transformed data and b is the corresponding fractional reduction in the original or untransformed data, then they are related as follows:

$$b = 1 - \exp[(1 - b')Y]/X \tag{1}$$

or

$$b' = 1 - \ln[(1 - b)X]/Y, \tag{2}$$

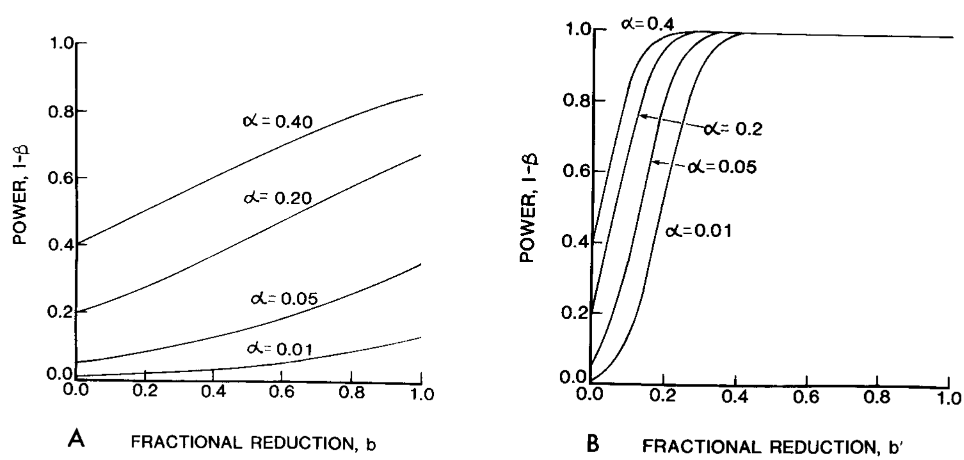

FIG. 2. Statistical power for testing the fractional reduction in abundance of age-1 Atlantic menhaden measured as (A) recruitment to age-1 with a coefficient of variation (CV) equal to 0.757 and 24 degrees of freedom and (B) natural logarithm of recruitment to age-1 with a CV equal to 0.076 and 24 degrees of freedom. Curves are presented for four levels of type I error (0.01, 0.05, 0.2, 0.4).

Table 2

Recruitment to age-1 of Atlantic menhaden (in millions) for the 1955 through 1979 year classes. Estimates based on virtual population analysis from Ahrenholz et al. (1987).

Year Class	Recruits to Age-1	ln (Recruits to Age-1)
1955	5,621	8.634
1956	7,154	8.875
1957	3,263	8.090
1958	14,767	9.600
1959	2,164	7.680
1960	2,959	7.993
1961	2,211	7.701
1962	2,223	7.707
1963	1,754	7.470
1964	1,938	7.569
1965	1,431	7.266
1966	2,002	7.602
1967	1,210	7.098
1968	1,711	7.445
1969	2,612	7.868
1970	1,382	7.231
1971	3,539	8.172
1972	2,760	7.923
1973	3,086	8.035
1974	3,867	8.260
1975	6,932	8.844
1976	5,297	8.575
1977	4,827	8.482
1978	4,404	8.390
1979	6,891	8.838
Mean	3,840	8.054
Standard deviation	2,908	0.615
Coefficient of variation	0.757	0.076

where X is the mean of the untransformed data and Y is the mean of the transformed data.

Results of this analysis (Table 3) suggest that we have a 50% chance of detecting a reduction in abundance in the 1984 year class of Atlantic menhaden presumed due to disease, if there is at least a 40% decline in catch in numbers at age-2 in 1986 or at least a 71% decline in the estimated recruitment to age-1 for the 1984 year class. Likewise, a 90% chance of detecting a reduction in abundance of the 1984 year class of Atlantic menhaden requires a 62% decline in catch in numbers at age-2 or an 88% decline in recruitment to age-1. Clearly as one is willing to accept an increasing type I error or decreasing statistical power (i.e., increasing type II error), the magnitude of the impact or decline that can be detected will decrease (Table 3).

DISCUSSION

The obvious problem in working with catch in numbers at age-2 as an index of abundance for age-2 menhaden is that these data are particularly sensitive to

Table 3

Statistical power and corresponding detectable fractional reduction in abundance of Atlantic menhaden as measured by catch in numbers at age-2 (b_c) and recruitment to age-1 (b_r) for three levels of type I error (0.05, 0.10, and 0.20).

Power	b_c	b_r
	Type I error = 0.05	
0.25	0.23	0.54
0.50	0.40	0.71
0.75	0.52	0.82
0.90	0.62	0.88
0.95	0.66	0.90
0.99	0.73	0.94
	Type I error = 0.10	
0.25	0.13	0.43
0.50	0.33	0.64
0.75	0.46	0.77
0.90	0.55	0.84
0.95	0.62	0.88
0.99	0.67	0.92
	Type I error = 0.20	
0.25	0.03	0.10
0.50	0.21	0.51
0.75	0.38	0.69
0.90	0.49	0.79
0.95	0.53	0.83
0.99	0.65	0.89

and confounded by fishing effort. The catch data for this analysis were restricted to a recent period (1973–1983) over which fishing effort was relatively constant (Ahrenholz et al., 1987). The major problem in working with recruitment to age-1 as an index of abundance for age-1 menhaden is the long time-lag associated with obtaining virtual population analysis estimates because the cohort over most of its lifespan must have entered the fishery.

Based on tagging results and geotemporal patterns in the length at age of fish in the catch, the Atlantic menhaden stock is considered one population (Nicholson, 1978). If the stock consisted of more than one population and the impact of the lesion disease was upon only one of these subpopulations, then the proportional loss to that subpopulation would be greater. If we were able to distinguish among two or more subpopulations and the historical coefficients of variation for the subpopulations were comparable to that observed for the single population hypothesis, then the reduction in the impacted subpopulation would be more readily detected.

Poor detectability suggests that alternative approaches are needed in place of these traditional indices of abundance. Approaches that reduce high background variability will lead to improvements in detectability. One approach would be to attempt to relate the index of abundance with one or more environmental variables, while another approach would be to employ time series analysis (Box and Jenkins, 1976) to remove trends and autocorrelations from the index. The purpose of these approaches is to reduce the amount of variability in the index of abundance that remains unexplained. Significant spawner-recruit relationship would reduce unexplained variance in recruitment data (recruits to age-1), although results to date have been marginally significant (Ahrenholz et al., 1987).

Any additional mortality to menhaden prior to the age they contribute to the index of abundance may cause the subsequent reduction in that index to be more easily detected. However, the ability to assign a specific cause to that reduction would be reduced. Thus, the confounding of two or more sources of mortality and subsequent combined reduction in an index of abundance may be detectable, but the specific cause for the reduction cannot be assigned. In the analysis presented in this paper, we assume that the only additional mortality to menhaden not previously included and reflected in the historical data base is the mortality resulting from ulcerative mycosis.

In conclusion, a catastrophic loss to the Atlantic menhaden 1984 year class (e.g., greater than a 50% loss in abundance of the 1984 menhaden year class from the entire Atlantic coast) would have to occur to be detectable at reasonable levels of statistical power (e.g., greater than 70% chance of detection), but more subtle reductions (e.g., less than a 25% loss to the Atlantic menhaden 1984 year class from the entire Atlantic coast) would undoubtedly go undetected (e.g., chance of detection less than 12%). Such difficulties in detecting reductions are typical of most fish stocks having comparable or larger inherent variability in recruitment or landings.

Acknowledgments: We thank the following reviewers for their critical comments on this manuscript: Dean Ahrenholz, Alex Chester, and Chuck Manooch. We also thank Herb Gordy for drafting the figures. Preparation of this paper was supported in part by a contract from the Ocean Assessments Division, National Ocean Service, National Oceanic and Atmospheric Administration.

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Received 28 November 1986